Dominant Frequency, Regularity and Organization Indexes Response to Preprocessing Filter Variations on Simulated Electrograms During Atrial Fibrillation

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Abstract: Atrial fibrillation (AF) is the most common tachyarrhythmia. An accurate AF diagnosis is based on electrograms (EGM) interpretation. In this work, we evaluated different preprocessing filters to calculate dominant frequency (DF), organization index (OI) and regularity index (RI) for EGM during AF, this comparative analysis has not been reported previously. EGM were obtained from AF simulated by a three-dimensional model of human atria. The preprocessing stage with a low-pass filter, rectification and high pass filter was implemented. Additionally, a test over 60 simulated signals using different filters with different orders was developed. It was found that some filters affect the DF calculation and cause a bimodal distribution in the DF histogram. Calculation of DF, OI and RI by Fast Fourier Transform analysis of preprocessing signals has high sensibility to filters settings. OI and RI analysis works properly in EGM with single potentials, however, DF is not necessary related with cycle length in fragmented EGM and OI calculation becomes inaccurate with high DF.

1 INTRODUCTION

Atrial fibrillation (AF) affects about 2% of the population and its incidence is increasing. The AF is characterized by rapid and chaotic electrical activity over the atria without the ability to generate effective atrial contraction. The accurate AF diagnosis is based on the interpretation of electrograms (EGM) recroded from different atrial zones. Cardiovertion, antiarrhythmic drugs and radiofrequency ablation are used like therapeutic methods in AF. Ablation could be improved with techniques of cardiac mapping obtained from intracardiac EGM recorder on atrial tissue in order to find areas with arrhythmogenic substrate. Thus, it is necessary to found a relationship between electrical propagation and EGM; however this is not entirely resolved.

Recent studies focus on the location of complex fractionated atrial electrograms (CFAE) as AF substrates looking for the ablation of these areas, specially for chronic AF, however nowadays this is an open problem. In order to find the relation between EGM and electrical propagation, some indexes have been developed, attempting to measure spatio-temporal organization of AF, which is related to repetitive morphology and high periodicity of the signals.

To measure the extent of spatial organization of atrial activation during AF, ()Botteron1995 proposed a preprocessing method for EGM. This is described as follows: First, Band-passed filtering with digital, zero phase, third-order Butterworth filter with cut-offs of 40-250Hz. Second, Absolute value (rectification). Third, Low-pass filter with Butterworth filter with cut-off of 20 Hz. This method has been used since 1995 to calculate different indexes: the dominant frequency (DF), organization index (OI) and regularity index (RI) (()Everett2001). (Everett et al., 2001) determined that to improve the Fast Fourier Transform) FFT performance in the preprocessing stage is necessary to use 4s or greater windowed signals.

DF, OI and RI are currently being used in clinical practice. However different authors have discussed the practical use of these indexes, because they are sensitive to the method of recording, signal-to-

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noise ratio (SNR), far field ventricular depolarization or complexity of the signal ((Elvan et al., 2009)). In this work, the sensitivity of these indexes was studied when the filters are setting in different ways in preprocessing stage and DF, OI and RI calculation was analyzed during CFAE.

2 METHODS

2.1 Atrial Fibrillation and Electrograms

A chronic AF episode was simulated in an anatomically realistic 3D model of human atria that includes fibers orientation, electrophysiological heterogeneity and anisotropy. Unipolar atrial EGM at 60 points of the left atrial surface (0.2 mm from the surface) were simulated each millisecond during 8 seconds (Tobón et al., 2010).

2.2 Dominant Frequency, Organization and Regularity Indexes

The DF was calculated using the definition given by (Everett et al., 2001), DF is the maximum peak in the power spectrum after apply a FFT with hamming window to the output of preprocessing stage define by (Botteron and Smith, 1995).

OI (Everett et al. 2001) is the ratio between the area under DF ± 0.75Hz including the areas under harmonic frequencies to DF between 3 to 20Hz and the total area as shown in the following equation:

$$OI = \frac{A(DF \pm 0.75) + \sum_{i=2}^{3} A[(DF * i) \pm 0.75]}{A(3 \text{ Hz to } 20 \text{ Hz})} \quad (1)$$

where A is a function that calculates the area and the harmonics are include only if the peak is less than 20Hz.

We use the RI index defined by (Sanders et al., 2005) like the ratio of spectral power in a 0.75Hz band centered at the DF and the total power between 3Hz and 20Hz.

3 RESULTS

The preprocessing method was tested with four different types of filters, with different orders, implemented in MatLab®. Butterworth, Chebyshev 1, Chebyshev 2 and elliptic filters were used. Low-pass filters between 2nd-order to 20th-order and band-pass filters between 4th-order to 40th-order were used. In each combination the band-pass order was twice the order of low-pass filter.

Figure 1 shows the histogram of DF calculation when were applied 76 combinations filters to the 60 simulated signals. The histogram shows that DF are mainly concentrated between 5.5 Hz and 6.5 Hz, however there are results between 11 and 13 Hz wich correspond to DF of five signals with high degree of fragmentation and with some specific filters.

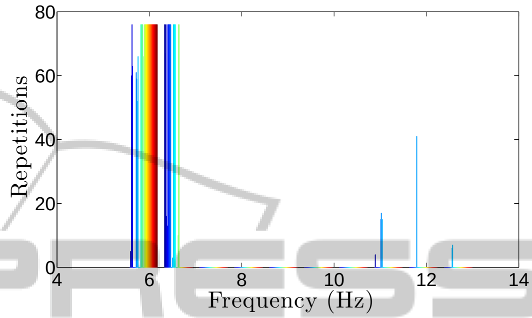

Figure 1: General histogram of DF calculation with 76 combination filter applied to 60 EGM signals.

Figure 2 shows four AF signals with their respective spectrum and DF histogram. The signal in Figure 2(a) is a regular EGM with single potential, DF calculation had the same result for each combination of filters, as seen in its histogram. Figure 2(b) shows two DF results depending on the used filters, however, the difference between them is barely 0.33 Hz. Figure 2(c) and 2(d) are CFAE signals corresponding to particulars combination of filter resulted in high DF, greater than 10Hz. Their power spectrums correspond to the set with high DF. These results show that response of DF analysis on CFAE signals is sensible to filters configuration.

2nd-order filters or higher than 6th-order filters in the low pass stage results in low DF in CFAE signals, consequently there is no relation between DF and CFAE signals. Also the relation between DF and cycle length is not clear. 3rd-Order and 4th-order Butterworth, Chebyshev 1 and Chebyshev 2 filters produced high DF in CFAE signals, which is appropriated if it is looking for a relation between DF and CFAE.

Table 1 shows the DF, OI and RI means for all filter combinations applied to signals showed in figure 2. EGM 2(c) and EGM 2(d) were separated in two sets, according to DFs value showed in their histograms. The variation of DF values yields a variation of OI and RI. In signals where DF $>$ 10 Hz are not possible to calculate OI because the harmonics are greater than 20Hz.

Figure 3(b) shows the power spectrum of the preprocessing EGM for an AF signal with CFAE using

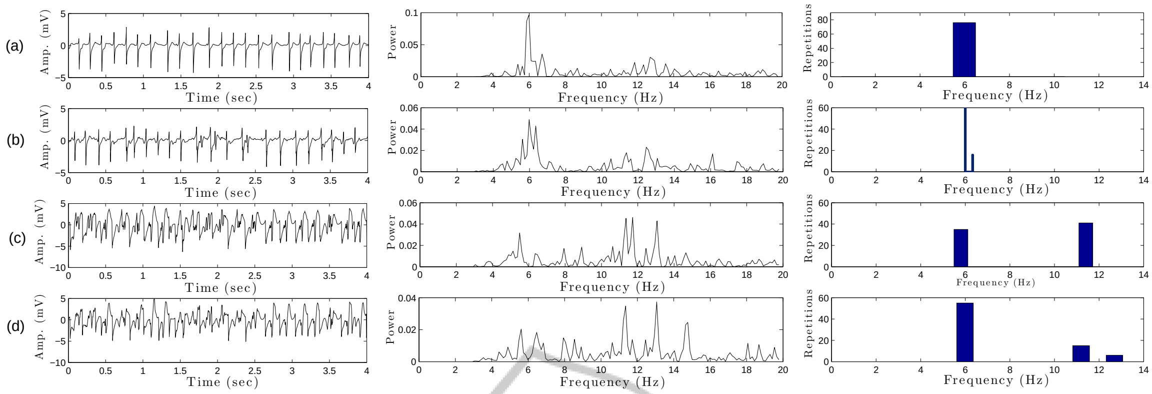

Figure 2: Four different EGM, their respective power spectrum and histogram.

Table 1: DF, OI and RI for signals showed in figure 2.

	DF (Hz)	OI	RI
EGM 3a	5.98	0.45	0.35
EGM 3b	6.06	0.43	0.35
EGM 3c-set1	11.72	–	0.17
EGM 3c-set2	5.48	0.36	0.18
EGM 3d-set1	5.66	0.34	0.15
EGM 3d-set2	11.84	–	0.14

a 2th-order Butterworth filter and Figure 3(c), a 4th-order Butterworth filter. Figure 3 indicate the sensitivity of the power spectrum when it was changed the order of the filter. This causes variations in the maximum peak affecting DF, OI and RI values presented in Table 2.

Table 2: DF, OI and RI for signal showed in figure 3.

Butterworth	DF (Hz)	OI	RI
2*nd*-order filter	6.35	0.26	0.14
4*th*-order filter	13.06	–	0.12

4 DISCUSSION

Several authors have used different filters in the pre-processing stage, (Everett et al., 2001) used a 2nd-order butterworth filters. (Barbaro et al., 2000) used 40th-order FIR filters, (Nguyen et al., 2009), other authors used the pre-processing method defined by (Botteron and Smith, 1995) but they did not define the order and type of filters. The present work has evidenced for the first time the importance of establishing the type and the order of the band-pass and low-pass filters in the pre-processing stage.

DF definition is based in the results of (Skanes et al., 1998) who concluded that DF is determined by the cycle length of AF spatio-temporal periodic activity. DF greater than 10 Hz resulted from CFAE has no physiological meaning related with cycle length, since high frequencies could be related with the complexity of the signal. This is supported by other authors who showed that there is a poor correlation between the EGM cycle length and DF in patients with persistent AF ((Elvan et al., 2009)). (Ng et al., 2007) demonstrated that although DF analysis can be reliably, used to measure local activation rate in ideal situations, several factors can contribute to the unpredictability of DF analysis related to recording techniques and signal properties. They suggested the use of well defined signal processing techniques and careful evaluation of the time domain signals.

In CFAE, independently of the filter used in the preprocessing stage, DF is not necessary related with cycle length. Depending on filters settings, DF could be related or not with complexity of the EGM, in any case the DF has no correlation with morphology of signals. DF by itself could not make any difference between a CFAE and a high frequency EGM with single potentials. RI defined by (Sanders et al., 2005) as an auxiliary index to ensure reliability in DF detection, such that DF calculation is accepted only if RI > 0.2 in order to reject signals with poor SNR. However, despite of using simulated free-noise EGM in present work, results gave RI < 0.2 in some cases, which correspond to signals with CFAEs. The OI was defined by (Everett et al., 2001) who showed that this index has a correlation with the periodicity and morphology of AF signal. However, in CFAE where DF > 10 Hz, It is not possible to calculate OI because the harmonics are greater than 20Hz.

As a future work we are testing DF, OI and RI on different simulated and real tachyarrhythmia signals. Additionally we are developing other indexes correlated with the morphology of the signals to characterize CFAE.

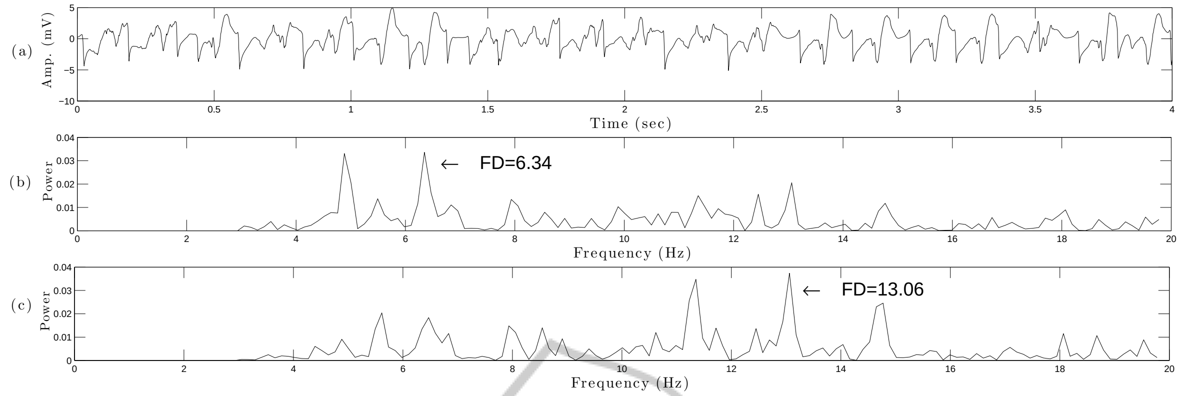

Figure 3: (a). EGM. (b). EGM power spectrum using 2-order Butterworth filters. (c). signal power spectrum using 4-order Butterworth filters.

5 CONCLUSIONS

Calculation of DF, OI and RI by FFT analysis of preprocessing signal using the (Botteron and Smith, 1995) method has high sensitivity to filters settings. Our results suggest that it is necessary to specify the filter configuration used in the pre-processing stage in order to avoid ambiguous results. OI and RI analysis works properly in EGM with single potentials, however, DF is not necessary related with cycle length in CFAE while OI calculation has problems with high DFs. In order to study CFAE we recommend keep researching and developing of other analysis tools.

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